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TWENTY-SECOND ANNUAL REPORT OF THE POWER AFFILIATES PROGRAM

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FOREWORD

This report provides a summary of the activities of the Power Affiliates Program (PAP) in the Department of Electrical and Computer engineering at the University of Illinois for the calendar year 2000. The information is intended to be a progress report to the affiliate companies listed below. The PAP is the foundation of the industrial liaison effort in the power and energy systems area. There are eleven active affiliates associated with the PAP. They are:

Ameren - UE
BP Amoco
Burns & McDonnell
Central Illinois Light Company
City Water, Light & Power
ComEd
Electrical Manufacturing & Coil Winding Association, Inc.
MidAmerican Energy
PowerWorld Corporation
S&C Foundation
Sargent & Lundy Engineers

2000 was an active year for the PAP and the highlights are covered in this report. We acknowledge the valuable support of the Affiliates and are most thankful to these companies for their continued support.

Patrick Chapman
George Gross
Stan Helm
Ian Hiskens
Phil Krein
Tom Overbye
M. A. Pai
Pete Sauer

1. INTRODUCTION AND SUMMARY

The Power Affiliates Program (PAP) was initiated in January 1979 as part of a major effort to strengthen the power and energy systems area. The original objectives were to

- Maintain stimulating, meaningful and high quality undergraduate and graduate programs in electric power engineering
- Increase university-industrial interaction at all levels of education and research in electric power engineering.

These objectives are as much valid today as they were in 1979. The multi-faceted activities in 2000 under the PAP umbrella clearly were in support of these objectives.

Throughout the past twenty-two years, the Power Affiliates Program has maintained a stable base during times of rapid change. This base provided the seed money for research, which led to additional funding by other sources. This base has also made it possible for students to be exposed to industrial problems and to participate in technical and professional meetings. With the cyclical nature of funding by government agencies, the Power Affiliates Program is a critically important source of support.

This annual report is organized as follows. A financial statement for the calendar year 2000 is given in Section 2. Section 3 describes how the power program fits into the departmental structure. There is no official degree or option associated with the Power Program, but there is a significant level of specialization which is possible in this area through a set of courses developed and offered by the group of faculty who constitute the Power and Energy Systems Area. Section 4 gives a brief description of the courses for specializing in electric power and tabulates the enrollment figures for the most recent offerings. Included in this section is an historical record of the number of graduates who have taken three or more of these courses. Section 5 lists the activities of both the students and the faculty members during the 2000 calendar year. Section 6 provides a brief summary of research projects that are funded by various sources. Section 7 gives information about the graduate students in the power area. In addition to personal data and interests, each student has written a brief abstract of his or her research work. Laboratories and other facilities of the power area are discussed in Section 8. The report concludes with a directory in Section 9 and list of publications in Section 10.

2. FINANCIAL STATEMENT

The following tabulation of income and expenditures for the calendar year 2000 was prepared from a detailed University statement as of December 31, 2000, Reference [1].

Income carried over from the calendar year 1999	$ -3,662
Total income during calendar year 2000	35,050
Total available income during calendar year 2000	$31,388

Expenditure	**Expenditure Amount**
Personnel and Services	$11,254
Materials/Supplies/Equipment	466
Transportation/Travel	4,024
Total expenditures	$15,744

Summary

Amount of funds available during calendar year 2000	$31,388
Amount of expenses during calendar year 2000	-15,744
Balance as of December 31, 2000	$15,644

3. THE POWER PROGRAM WITHIN THE DEPARTMENT

Electrical engineering undergraduate students are required to complete 128 hours of course work for a B.S.E.E. degree. Detailed descriptions of the undergraduate program and suggested curriculum in Power are given in Reference [2]. All M.S.E.E. students are required to complete a minimum of 8 units (32 credit hours) including a graduate thesis. All Ph.D. students must qualify through a written examination and complete course and thesis requirements. A detailed description of the graduate program is given in Reference [3].

The Electrical and Computer Engineering Department is subdivided into eight distinct technical areas as follows:

Bioengineering and Acoustics
Circuits and Signal Processing
Communication and Control
Computational Science and Engineering
Computer Engineering
Electromagnetics, Optics and Remote Sensing
Microelectronics and Quantum Electronics
Power and Energy Systems

While the Department does not have official degree-granting options in each of these areas, in practice, the eight areas serve as the appropriate grouping of the faculty activities and interest. In terms of size, the Power and Energy Systems area represents about 8% of the total active faculty and about 10% of the total student enrollment. The faculty committee in each area has the responsibility for administering courses and research in that area within the Department.

The Power and Energy Systems Area Committee and associated faculty for the 2000 - 2001 academic year together with their general interests are:

P. Chapman	(machines, power electronics, circuits)
G. Gross	(power system economics, planning and operations; electric regulatory policy; industry restructuring; competitive market mechanisms)
M. S. Helm, Emeritus	(power system analysis)
I. A. Hiskens	(power system dynamics)
P. T. Krein	(power electronics, machines, electrostatics)
T. J. Overbye	(dynamics, stability and operations of power systems)
M. A. Pai	(dynamics, stability and computational methods in power systems
P. W. Sauer	(modeling and simulation of machines and power systems)

Two of the primary responsibilities of the Power and Energy Systems Area Committee are to improve, keep current and staff the courses assigned to the Power and Energy Systems Area. In 2000-2001 those courses were

ECE 271GG	Engineering Decision Techniques
ECE 330	Power Circuits and Electromechanics
ECE 333	Electric Machinery (with laboratory)
ECE 336	Advanced Electromechanical Energy Conversion
ECE 364	Power Electronics
ECE 369	Power Electronics Laboratory
ECE 371AHV	Advanced Hybrid Automotive Systems
ECE 371HEV	Hybrid and Electric Automotive Systems
ECE 376	Power System Analysis I
ECE 378	Power System Analysis II
ECE 468	Modeling and Control of Electromechanical Systems
ECE 473	Operation and Control of Power Systems
ECE 476	Dynamics and Stability of Power Systems
ECE 488	Electricity Resource Planning
ECE 490I	Power and Energy Systems Area Seminar
ECE 497PH	Hybrid Systems Analysis of Power System Dynamics
ECE 497PE	Power Electronic Drives and Systems
ECE 497PS	Power System Modeling and Analysis
ECE 497TO	Issues in Competitive Electricity Markets

The three hundred level courses are advanced undergraduate or beginning graduate courses, while the four hundred level courses are graduate. Of these courses, ECE 371AHV, ECE 371HEV, ECE 468, ECE 473, ECE 488, and ECE 497PH were not taught during the 2000-2001 academic year. The Power and Energy Systems Area Committee periodically evaluates each course outline for possible revision for future offerings. A brief description of each of these courses, together with the enrollment of the past year, is included in the next section. In addition, power area faculty are active in ECE 345, Design Projects. This is the capstone design course for our seniors.

4. COURSES AND ENROLLMENT

As one of eight major areas in Electrical and Computer Engineering, the Power and Energy Systems Area is responsible for the development and offering of a considerable number of courses. The current courses assigned to the power area are described briefly below. The total enrollment for courses offered in the academic year 2000-2001 is also given for each course.

ECE 271GG Engineering Decision Techniques

This course is concerned with modeling of decisions and analysis of models to develop a systematic approach to making decisions. The focus is on the development of techniques for solving typical problems faced in making engineering decisions in industry and government. Topics include resource allocation, logistics, scheduling, sequential decision-making and explicit consideration of uncertainty in decisions. Extensive use of case studies gets students involved in real world decisions. The course has two required texts: Operations Research: Principles and Practice, A. Ravindran, D. T. Phillips and S. S. Solberg and Making Hard Decisions: An Introduction to Decision Analysis, R. T. Clemen. The total enrollment for the academic year 2000-2001 was 28.

ECE 330 Power Circuits and Electromechanics

ECE 330 is a course in power circuits and electromechanics. It is a new course after the restructuring of the undergraduate curriculum. The course starts with a review of phasors followed by three phase power circuits, mutual inductance, magnetic circuits and transformers. Electromechanical systems are analyzed using energy balance concepts. Introduction to synchronous, induction, dc and small machines is given. The required text was Foundations of Electric Power by I. R. Cogdell. The total enrollment for the academic year 2000-2001 was 159.

ECE 333 Electric Machinery

This four-hour course contains a laboratory one credit hour component, which is an elective in a list of 14 from which students select two. The fifteen experiments typically include power measurement, power factor correction, transformer characteristics, three-phase transformer connections, induction motor tests, induction motor torque-speed characteristics, synchronous machine tests, synchronous machine power characteristics, digital simulation of machine dynamics, motor control, and a written plus oral project presentation on power and energy system topics. The required text was Electric Machinery Fundamentals, 3rd edition, by S. J. Chapman. The total enrollment for the academic year 2000-2001 was 36.

ECE 336 Advanced Electromechanical Energy Conversion

This three-hour course contains advanced theory and analysis of rotating and linear machines and drives. It includes power electronic drives for dc and ac motors. The analysis uses d-q transformations and related techniques. Emphasis is placed on the time scale modeling of electromechanical devices and on their function in drives. The required text was Analysis of Electric Machinery, by P.C. Krause and O. Wasynczuk, IEEE Press. The total enrollment for the academic year 2000-2001 was 5.

ECE 364 Power Electronics

This three-hour course is a comprehensive treatment of switching power conversion systems and the devices used to build them. Concepts of switch control are developed from general switching functions. Phase control, pulse width modulation, and phase modulation are studied for applications in all types of converters. Converter topologies are introduced along with design concepts for power filters and interfaces. Devices such as diodes, thyristors, bipolar transistors, field effect transistors, capacitors, and magnetic components are examined in the context of high-power switching applications. The required text was Elements of Power Electronics by P. T. Krein. The total enrollment for the academic year 2000-2001 was 27. The course is also available by web-based education.

ECE 369 Power Electronics Laboratory

This two-hour course is a laboratory study of circuits and devices used for switching power converters, solid-state motor drives, and power controllers, including dc-dc, ac-dc, and dc-ac converters and applications. It includes high-power measurements for silicon-controlled rectifiers, diodes, capacitors, power transistors and magnetic components. The course is designed to accompany ECE 364. A lab manual by P. Krein is used for the course. The total enrollment for the academic year 2000-2001 was 14.

ECE 371HEV/ME 393DRW Hybrid and Electric Automotive Systems

This four-hour course is a large-team design program directed at advanced vehicle technology and automotive electronics. A multidisciplinary team addresses all the design, implementation, and operating issues for a high-performance practical hybrid automobile. Students learn about physical and engineering considerations in battery systems, electric traction, engines, emission controls, and other automotive system issues. This course was not offered during the academic year 2000-2001.

ECE 371AHV/ME 393AHV Advanced Hybrid and Automotive Systems

Design, operation, and systems issues associated with automobiles that combine a combustion engine with an electrical system. Major sub-systems including engine and emission controls, inverters and electric machines, batteries and energy management, dynamic operation, and structural considerations. In this course, students are expected to build and operate working subsystems. There is emphasis on testing, data analysis, and modifications to achieve defined engineering objectives. Laboratory work involves parametric studies and experiments with vehicle sub-systems and complete vehicles. This course was not offered during the academic year 2000-2001.

ECE 376 Power System Analysis I

This three-hour course is the first of two courses on power system analysis. Topics included are transmission line parameter calculations, equivalent circuits, network analysis, load flow, fault analysis, symmetrical components, unsymmetrical fault analysis, and introduction to economic dispatch. The course is designed to be a stand-alone introduction to the fundamentals of power system analysis and provide the basis for all subsequent courses in the power system analysis. The required text in the academic year 2000-2001 was Power System Analysis, 2nd edition, by Bergen and Vittal. The total enrollment for the academic year 2000-2001 was 35. This course is also available by web-based education.

ECE 378 Power System Analysis II

This three-hour course is the second of two courses on power system analysis. Topics included are economic operation of power systems, optimal load flow concepts, automatic generation control, state estimation, classical transient stability, modeling for dynamic and transient stability, and d-c transmission. The recommended text is Power Generation, Operation and Control, 2nd edition, by Wood and Wollenberg. The total enrollment for the academic year 2000-2001 was 11.

Graduate Courses:

ECE 468 Advanced Modeling and Control of Electromechanical Systems

This course addresses issues of electrical drives in a modern control and circuit framework. Dynamic models of electric machines are presented. There is special emphasis on field-oriented control methods for ac motors. Power electronic systems for high-performance drives are studied. Nonlinear system methods such as periodic transformations, averaging, geometric control, and feedback linearization are presented. Special topics covered include electrostatic micromachines and permanent magnet machines. Internal notes by P. Krein are available for the course. The course was not offered during the academic year 2000-2001. The course has been produced on videotape.

ECE 473 Operation and Control of Power Systems

The course includes energy control center functions, power system operating states, supervisory control and data acquisition, state estimation, on-line load flow, security assessment, economic dispatch, automatic generation control, optimal power flow, security constrained economic dispatch, multistage rescheduling and equivalents. The course was not offered during the academic year 2000-2001.

ECE 476 Dynamics and Stability of Power Systems

The course includes the dynamic representation of interconnected power systems - electrical plus mechanical, linearized dynamic models of multimachine systems, methods of coherency identification, order reduction by singular perturbation, time scale decomposition and aggregation techniques, dynamic equivalents, direct methods of stability analysis and power system stabilizer design. The current course text is the book "Power Systems Dynamics and Stability" (Prentice Hall 1998) by P. W. Sauer and M. A. Pai. The total enrollment for the academic year 2000-2001 was 10. This course is also available by web-based education.

ECE 488 Electricity Resource Planning

This course provides coverage of the basic techniques in electric utility resource planning including methodologies for reliability evaluation and assessment, production costing, marginal costing, supply-side and demand-side planning and integrated resource planning. Throughout the course, probabilistic approaches are emphasized. In place of a text, notes specifically prepared by George Gross are used. The course was not offered during the academic year 2000-2001.

ECE 490I Power and Energy Systems Area Seminar

This course is a graduate seminar on advanced topics of current interest. Both faculty and students participate by presenting either current research results or topics of interest in journal publications. Guest speakers from industry and other universities are also scheduled periodically throughout the semester. The total enrollment for the academic year 2000-2001 was 26.

ECE 497PH Hybrid Systems Analysis of Power System Dynamics

The purpose of the course is to present a new approach to the analysis of large scale complex networks, such as power systems, by viewing them as interconnections of dynamic devices, discrete devices and algebraic constraints. Such hybrid systems can display very interesting forms of behavior. Trajectory sensitivity analysis used as a tool for security monitoring, stability analysis and model verification. Aspects of hybrid system control are presented. The course was not offered during the academic year 2000-2001.

ECE 497PS Power System Modeling and Analysis

This is a newly developed half-semester graduate course in the modeling of power systems in the steady state and dynamic regimes. It includes the analysis and simulation techniques for power and power electronic systems as well as computational issues in power systems and power electronics. Topics covered are: advanced power flow, sparsity techniques, power flow control, least squares and estimation applications averaging techniques for power electronic systems, numerical integration of differential equations. The course uses the notes of George Gross in lieu of a text. The total enrollment for the academic year 2000-2001 was 8.

ECE 497PE Power Electronic Devices and Systems

This advanced course in power electronics considers the unique devices and models used for switching energy conversion systems. Emerging nonlinear approaches to operation and control are discussed. Design issues for fast dynamic converters are presented. The goal of the course is to provide students with a rich background in the broad issues of high-performance power electronics at the graduate level. Specific topics include magnetic device design, power semiconductor device models, interfaces and gate drives, small-signal and large-signal converter control models. Averaging methods are presented for power converters. Concepts and methods of geometric control are addressed. The required text is Elements of Power Electronics by P.T. Krein. The total enrollment for the academic year 2000-2001 was 11.

ECE 497TO Issues in Competitive Electricity Markets

This course provides an introduction to competitive electricity markets. The course covers topics including market structures and paradigms, transmission services, transmission congestion management, allocation of real power losses, optimal bidding strategies, and market power analysis. The total enrollment for the academic year 2000-2001 was 12.

NUMBER OF ELECTRIC POWER AND ENERGY SYSTEM AREA GRADUATES IN RECENT YEARS

1950-1970 Annual Average Power Area Graduates

B.S.E.E.	-	25
M.S.E.E.	-	3

1970-1980 Annual Average Power Area Graduates

B.S.E.E.	-	44
M.S.E.E.	-	7

1980-1990 Annual Average Power Area Graduates

B.S.E.E.	-	32
M.S.E.E.	-	5
Ph.D.	-	2

1990-1995 Annual Average Power Area Graduates

B.S.E.E.	-	40
M.S.E.E.	-	6
Ph.D.	-	2

1995-2000 Annual Average Power Area Graduates

B.S.E.E.	-	35
M.S.E.E.	-	9
Ph.D.	-	3

2000-2001 Annual Average Power Area Graduates

B.S.E.E.	-	36
M.S.E.E.	-	8
Ph.D.	-	3

5. ACTIVITIES

The faculty and students in the Power and Energy Systems Area participated in a considerable number of special activities during the calendar year 2000. The major events are listed below:

- Dr. Vincenzo Galdi, Assistant Professor, University of Salerno, Dr. Ettore Bompard, Assistant Professor, Politecnio of Torino, and Andrea Fossa, University of Pavia, are visiting the Power and Energy Systems Area in the academic year 2000-2001.
- George Gross spent the academic year 1999-2000 on sabbatical in Italy with visiting appointments at the Politecnico di Milano, Politecnico di Torino and University of Pavia. He lectured at various campuses and research organizations.
- George Gross became a member of the Editorial Committee of Electra, the official publication of CIGRE.
- George Gross was invited to present a seminar at Hong Kong Polytechnic University, Hong Kong, January 2000.
- George Gross gave an invited presentation to the German section of the IEEE, January.
- George Gross was an external thesis examiner at Hong Kong University in January.
- M. A Pai reviewed research interests with faculty at University of California Irvine in January.
- Hawaiian International Conference on System Sciences, Maui, HI, January.
  - Tom Overbye and Pete Sauer presented papers.
- Tom Overbye reviewed the power system visualization with the Tennessee Valley Authority in Chattanooga, Tennessee in January.
- IEEE Power Engineering Society 2000 Winter Meeting, Singapore.
  - Ian Hiskens and Tom Overbye presented papers
  - George Gross attended committee meetings and participated in the technical sessions.
  - Karl Reinhard participated in the meetings.
- Tom Overbye reviewed power system visualization with Entergy in New Orleans in February.
- George Gross presented an invited lecture at ERSE, the Energy Regulatory Commission of Portugal, February.
- Eric Thomas attended a seminar for modeling and simulation of motion and power electronics in Indianapolis, Indiana in February.
- Pete Sauer participated in the PSERC Executive Committee meeting in New Orleans, February.
- Philip Krein attended an IEEE Technical Activities Board Meeting in New Orleans, Louisiana, February.
- Philip Krein attended the IEEE Applied Power Electronics Conference and chaired the PEL AdCom Meeting, New Orleans, Louisiana, February.
- Pete Sauer participated in the planning meeting for Carnegie Mellon University to become a member of PSERC, Pittsburgh, Pennsylvania, February.
- Pete Sauer participated in a PSERC Special Committee Meeting in New Orleans, Louisiana in February.

- Tom Overbye presented a short course and discussed power system visualization at TVA, Chattanooga, Tennessee in March.
- George Gross was a presenter at a short course on electricity restructuring in Grenoble, France; the course was organized by the French chapter of IEEE, March.
- Philip Krein with seven ECE 371 AHV students attended and displayed the hybrid car at the 2000 Society of Automotive Engineers Congress in Detroit Michigan in March.
- Philip Krein, Eric Thomas, and Cory Papenfuss conducted motor tests for the hybrid car at Danfoss Electronics, Inc., Rockford, Illinois, March.
- George Gross hosted the Power System Planning and Operations School, Houston TX in March.
  - Tom Overbye gave a presentation.
- Engineering Open House.
  - ECE 333 students presented machinery demonstrations.
- ECE 333 and ECE 378 student class trip to S&C Electric Co. and the Zion generating station.
- American Power Conference, April.
  - Stan Helm coordinated the UI participation in the sponsored student, sponsored faculty program.
  - Eleven students and faculty were sponsored by ComEd, Doyen and Associates, Inc., MidAmerican Energy, Sargent and Lundy, Soyland Power Cooperative.
  - The faculty attending were Stan Helm, Pete Sauer, and George Gross.
- Grainger Awards were presented to 20 graduating BS, MS and Ph.D. students in power in April.
- Pete Sauer and Tom Overbye participated in an NSF Workshop on Research Needs in Power Systems, Washington DC, April.
- Pat Chapman participated in the Naval Symposium on Electrical Machines, April.
- CIGRE, Paris France, April.
  - George Gross is a member of the Executive Committee of the U.S. National Committee of CIGRE with responsibility for strategic planning.
  - George Gross is an Expert Advisor to the U.S. Representation for CIGRE Technical Committee number 39.
  - George Gross was appointed Vice Chairman of ACCOPE, the Committee changed with assessing the future publication policies of CIGRE, the international council on high voltage networks.
- Ian Hiskens presented a seminar at the University of Washington, April.
- George Gross was the keynote speaker at the national meeting of the Italian association of power systems specialists in Naples in May.
- Pete Sauer, Tom Overbye, and Ian Hiskens participated in the PSERC IAB meeting in Ames, Iowa, May.
- Ian Hiskens attended the International Symposium on Circuits and Systems and presented a paper, Geneva Switzerland, May.

- George Gross gave an invited talk at the Swiss Federal Institute of Technology (ETH) in June, and discussed research topics with colleagues.
- Pete Sauer participated in the EPRI/DoD project review meeting in Palo Alto, CA, June.
- Tom Overbye discussed visualization work with CWLP, June.
- Philip Krein chaired the IEEE Power Electronics Society AdCom meeting, presented a paper, chaired a session and participated in a panel at the Power Electronics Specialists Conference, Galway, Ireland, June.
- Philip Krein participated in the IEEE TAB meeting Vancouver, BC, June.
- Tom Overbye discussed visualization work with NYSEG, Binghampton, NY, June.
- Tom Overbye discussed visualization work with WAPA, Denver CO, June.
- Tom Overbye discussed visualization work with Entergy, Pine Bluff, AR, July.
- Philip Krein and two students presented papers at the IEEE Workshop on Computers in Power Electronics, Blacksburg, VA, July.
- IEEE Power Engineering Society Summer Meeting, Seattle, July.
  - Tom Overbye presented a paper, co-taught a short course and attended committee meetings.
  - Pete Sauer, Stan Helm and George Gross participated in committee meetings.
  - T. Nguyen and D. Chaniotis presented papers.
  - Ian Hiskens presented a paper and visited Alstom Esca.
  - Pete Sauer attended the PES sponsored teaching workshop, visited Boise State University, and participated in the IEEE PES Chapter's Congress.
- Pete Sauer, Tom Overbye, Ian Hiskens and George Gross participated in the PSERC retreat in Steamboat Springs, CO, July.
- Patrick Chapman was hired as visiting assistant professor, August.
- George Gross and Tom Overbye participated in a workshop on markets for electricity economics and technology, Stanford University, Palo Alto CA, August.
- Philip Krein participated in the IEEE TAB retreat, Dallas, TX, August.
- Tom Overbye participated in a CERTS meeting in Chicago, September.
- Philip Krein presented a paper at the IEEE INTELEC conference and chaired the IEEE PEL AdCom meeting in Phoenix, AZ, September.
- Tom Overbye provided testimony to Illinois Pollution Control Board, Joliet IL, September.
- Ian Hiskens presented a paper at the IEEE Conference on Control Applications, Anchorage, AK, September.
- Tom Overbye presented a paper at the IEEE Information Visualization Conference, Salt Lake City, UT, October.
- George Gross visited EEI, in Washington D.C., to discuss the School on Power System Planning and Operations, October.
- Pete Sauer visited Powertech Corporation in Vancouver, BC about the PSERC project on Integrated Security Analysis, September.

- North American Power Symposium (NAPS), Waterloo, Canada, October.
  - Pete Sauer, Tom Overbye, Ian Hiskens and Santiago Grijalva attended.
  - Ian Hiskens presented a paper.
  - Santiago Grijalva presented two papers.
  - Tom Overbye chaired a session and presented a paper.
- Electrical Manufacturers and Coil Winding Association and Conference Exposition in Cincinnati, Ohio, October.
  - Pete Sauer and 12 students participated; two students presented papers.
- Pete Sauer participated in a research proposal planning meeting at Cornell University in Ithac, NY, October.
- Ian Hiskens presented a seminar at Iowa State University, Ames, IA, October.
- Pete Sauer participated in the main IEEE Fellow Committee meeting, Newark, NJ, October.
- George Gross was invited to address the NSF Sustainable Energy Systems Workshop held at the Georgia Tech. Campus in Atlanta, November.
- George Gross made a video presentation for satellite broadcast for the National Technical University network, November.
- Pete Sauer, Ian Hiskens and Tom Overbye participated in an NSF Workshop on Future Directions for Complex Interactive Electric Networks, Washington DC, November.
- Philip Krein attended the IEEE TAB meeting in Tampa, FL, November.
- Pete Sauer made a presentation on the IEEE Fellow program to the RAB and TAB in Tampa Fl, November.
- George Gross made a presentation at McGill University and discussed research with colleagues at Montreal, Canada, November.
- Pat Chapman participated in the ESAC Industrial Affiliates Program meeting at Purdue University, West Lafayette, IN, November.
- Jason Wells and Seth McElhinney attended the ESAC meeting and short course on simulation, West Lafayette, IN, November.
- Pai was a thesis examiner at the Royal Institute of Technology, Stockholm Sweden, November.
- Philip Krein and Rob Balog participated in an NSF workshop, Orlando FL, November.
- George Gross was invited to address the IEEE Central Illinois Section in December.
- Pete Sauer and Tom Overbye participated in the PSERC IAB meeting in Denver, CO, December.
- Ian Hiskens attended the IEEE CDC conference in Sydney, Australia, December.
- Pat Chapman attended the Naval Symposium on Electric Machines and presented a paper, December.
- National Power System Conference (NPSC 2000) Bangalore, India, December.
  - V.Donde and M.A. Pai presented papers.

- Ian Hiskens served as the Secretary, Power Systems and Power Electronic Circuits Technical Committee of the Circuits and Systems Society.
- Ian Hiskens served as the convenor of the Task Force on Benchmark Systems, Stability Controls Subcommittee of the IEEE PES.
- M. A. Pai is the series Editor for the research monograph series in Power Electronics and Power Systems for Kluwer Publishers.
- Philip Krein served a term as President of the IEEE Power Electronics Society.
- Dr. Vincenzo Galdi, Assistant Professor, University of Salerno, Dr. Ettore Bompard, Assistant Professor, Politecnio of Torino, and Andrea Fossa, University of Pavia, are visiting the Power and Energy Systems Area in the academic year 2000-2001.
- George Gross spent the academic year 1999-2000 on sabbatical in Italy with visiting appointments at the Politecnico di Milano, Politecnico di Torino and University of Pavia. He lectured at various campuses and research organizations.
- George Gross became a member of the Editorial Committee of Electra, the official publication of CIGRE.
- Hosted the following guest speakers
    - Peter Sokolowski, “Symbolically Assisted Simulation of Power System Dynamics”, February.
    - Mustafa Khammash, ISU (via internet), "Calcium Homeostasis: A Feedback Control Point of View," February.
    - Prof. Venkat Anantharam, U.C. Berkeley (via internet), "Charge-Sensitive TCP and Rate Control in the Internet," March.
    - Eric Cunningham and Roy Rasmussen, "Hamilton Sundstrand Variable Frequency Generator," March.
    - Prof. John Guckenheimer (via internet), “Computing Periodic Orbits and Their Bifurcations," April.
    - Graham Rogers, "Robust Damping Controls for Power Systems," April.
    - David J. Perreault, "New Developments in Automotive Power Generation and Control," April
    - Prof. Leigh Tesfatsion, "Agent Based Computational Economics," April.
    - Vahe Caliskan, "Dual/High Voltage Automotive Electrical Power System Architectures," April.
    - Patrick Chapman, "Enhanced Performance of Electric Drives by Variable Waveshape Control," May.
    - Prof. David Hill, “Coordinated Optimal Voltage Control of Power Systems,” May.
    - Prof. James D. McCalley (via internet), “Security Assessment: Decision Support Tools for Power System Operators,” September.
    - Massoud Amin, “The EPRI/DoD Complex Interactive Networks/Systems Initiative,” September.
    - Steve Terelmes, “Scheduling Electricity in the Changing Electric Environment,” September.

- Prof. Maurizio Delfanti, "Facts Devices for Optimal Control of Power Flows with (N-1) Security Constraints," October.
- Mariesa Crow, "Integration of FACTS and Battery Energy Storage," November.
- Prof. Thomas Habetler, "Incipient Fault Detection In Induction Motors," November.

- Presented the following seminars by UIUC faculty and students:
  - Ian Hiskens, "Bounding Uncertainty in Power System Dynamic Simulations," January.
  - Karl Reinhard, "Using Distribution Factors for Contingency Analysis", February.
  - Shu Tao, "Congestion Management Allocation in Multiple Transaction Networks," February.
  - Daniel Logue, "Simulation of Vector Controlled Induction Machine Drives," February.
  - Rob Balog, "Coupled Inductors As A Basic Filter Block With Applications In Power Electronics," March.
  - Mike Kukovec, "Power Transmission Line Equivalent Circuit Models In Transient Analysis, March.
  - Dimitrios Chaniotis,"Iterative Linear Solvers for Ill-Conditioned Systems - Application to the Dynamic Simulation of Power Systems," April.
  - Trong Nguyen, "Direct Computation of Critical Clearing Time Using Trajectory Sensitivities," April.
  - Craig M. Martini, "Visualization of Power System Oscillation Modes and Participation Factors," May.
  - Pat Chapman, "Switched Reluctance Motor Drives and Their Control," August.
  - Vaibhav Donde, "Simulation of Bilateral Contracts In An AGC System," September.
  - Richard Engelbrecht-Wiggans, "An Introduction to the Theory of Ascending-Price Auctions, October.
  - Santiago Grijalva, "Complex Flow Network Limits and Static System Collapse," October.
  - Dan Logue, "Optimization of Power Electronic Systems Using Ripple Correlation Control," October.
  - Philip Krein, "The Hybrid Cars Are Here," October.
  - Rob Balog, "Coupled Inductors As A Basic Filter Block With Applications In Power Electronics," October.
  - Dimitrios Chaniotis, "Exploring Efficient Methods To Compute Trajectory Sensitivities for Power Systems," November.
  - Pedro Correia, "Strategic Equilibria In Competitive Electricity Markets," November.
  - Jamie Weber, "Efficient Available Transfer Capability Analysis Using Linear Methods," November.
  - Trong Nguyen, "Sensitivity Approach for Direct Computation of Critical Parameter Values in Power Systems," December.

6. RESEARCH FUNDED BY OTHER SOURCES

The Power Affiliates Program is a source of seed money, which enables the faculty to obtain support from major funding agencies. The following pages summarize the projects, which have been made possible through this growth.

A Hybrid Approach to Transport Industry Modeling – A Power System Viewpoint

M. A. Pai,* I. A. Hiskens,* V. Donde, W. Tangmunarunkit

National Science Foundation, ECS 0085755

With the emerging restructured nature of the power industry, there is a need to look at new approaches to modeling as well as tools of analysis. Among the transport industries, the power industry can both profit from the experience of other deregulated industries, as well as offer new ideas in terms of modeling and analysis. Increasingly, discrete events affect the performance of systems in real time. Such events are common in the physical system, for example relays, tap-changing transformers, and FACTS devices. However, the rules underlying the market layer also introduce discrete events. System performance under these conditions, where continuous dynamics and discrete events interact, is the principal focus of the proposal. A major theme is to map formal languages that describe hybrid systems, such as Petri nets and finite state automata, into a differential-algebraic model structure. A linking strategy will be exploited to maximize model flexibility. We shall also focus on trajectory sensitivity analysis of hybrid systems. The results of research will be in the form of formulating new areas of research for the restructured power industry.

Active Vibration Mitigation in Electric Drives Systems

P.L. Chapman, S.A. McElhinney

Grainger Center for Electric Machines and Electromechanics

Vibration of electric machines has many detrimental effects, including acoustic noise and mechanical wear. Since there is an increasing trend in industry to utilize power electronics for torque/speed control, it is logical to consider using the electronics for vibration mitigation as well. By detailed study of the mechanical properties of the machinery at hand, and by utilization of appropriate sensors, at least some of the noise can be eliminated. The goal of the project is to create a prototype system that will be significantly less noisy than a system without the proposed control.

Applications of GaN Technology to Power Electronics

P.L. Chapman, K. Kim

Grainger Center for Electric Machines and Electromechanics

Recent advances in GaN semiconductor devices will enable new developments in the power electronics area. GaN diodes and transistors can operate at higher temperature, speed, and voltage than the Si counterparts. This project will investigate the use of these devices in several typical power electronics applications, as well as at least one application not previously possible with Si technology.

Autonomous Optimal Control of Induction Machine Drives

P.L. Chapman, P.T. Krein, J.R. Wells

Grainger Center for Electric Machines and Electromechanics

Direct Torque Control (DTC) of induction machine drives is a straightforward method of decoupling torque and flux that in itself provides for fast response and minimal parameter sensitivity. However, setting the flux command in DTC for optimal efficiency, like most other methods of optimal control of induction machine drives, relies heavily on parameterization or involves sacrificing response time. A parameter insensitive optimization routine, known as ripple correlation control, that interferes minimally with the dynamic response of the system has been developed. The control utilizes the perturbations inherent in power electronics driven motor drives to test for optimality of the operating point. Since the perturbations are at high frequency, the optimization has high bandwidth. The machine parameters are not critical in this robust control.

Available Transfer Capability of Power Systems

P. W. Sauer,* S. Grijalva

National Science Foundation, EEC 96-15792

This project examines new approaches to the rapid computation of available transfer capability in electric power systems. It focuses on efficient techniques to simultaneously include thermal, voltage, voltage collapse, and transient stability margin constraints. New approaches to quantify the transmission reliability margin and capacity benefit margin are investigated.

Battery Equalization in Series Strings

P. T. Krein,* S. West

S & C Electric Co.; Grainger Endowment

Batteries are usually used in series strings. When a string is charged, the individual cells can become mismatched. Over time, this mismatch can grow, particularly if extreme temperature conditions occur. Mismatch is corrected by equalization, in which the battery voltages are forced to match. This is usually accomplished with a forced-overcharge process, with elevated voltage applied after the end of a charge cycle. This project studies an elegant equalization method invented at the U of I. In this method, a capacitor string is switched between adjacent batteries, forcing them to reach a matching condition whether or not they are charging.

Congestion Management Scheme for Multi-Transaction Systems

G. Gross,* S. Tao

EPRI/DoD

We are investigating the allocation of charges for congestion management (CM) in multiple transaction networks. The problem is formulated in two stages -- congestion allocation stage and congestion relief. In the congestion allocation stage, the operator determines the congestion burden attributable to each individual transaction. In the congestion relief stage, the operator used an adjustment bidding to determine the congestion relief actions. The allocation scheme is being tested on several systems.

Coupled Filter Applications to DC Power Converters

P. T. Krein,* D. C. Hamill (Surrey), R. Balog

Grainger Endowment in collaboration with the University of Surrey, England

Coupled magnetic filters offer performance improvements in dc switching power circuits, but are not well understood in the field. In fact, one key coupled filter building block has been reinvented several times over an interval of 60 years or more. This work seeks a fundamental understanding of coupled filter design, performance, and applications. Coupled filters are compared with more conventional approaches for design sensitivity and utility.

Development of an Analytical Framework for Strategic Bidding in Competitive Electricity Markets: Modeling and Policy Analysis

George Gross, George Deltas UIUC Department of Economics and Manho Joung

National Science Foundation, ECS-0000577

The work is on the design, functioning and performance of competitive mechanisms in wholesale electricity markets taking explicit account of the specific characteristics and constraints of electrical generation and consumption. The objective is to develop a very general and comprehensive analytic framework that integrates the game theoretic aspects of electricity exchanges with the unique constraints under which electric power systems operate. This framework will lay the foundation for the evaluation of various designs for electricity market structures and 'rules of the road' of auction mechanisms that incorporate the constraints imposed by the physical/engineering/operational constraints inherent in electricity systems, so as to maximize economic efficiency. The in-depth analysis of the structural characteristics of electricity markets will provide a basis for the formulation of optimal bidding/offering strategies with both supply- and demand-side bidders. We aim to use the framework to address the various aspects of the implementation and performance of auctions for electricity; the explicit incorporation of uncertainty; the interrelationships between the MWh commodity markets and specific markets in ancillary services; and, the impacts of longer term forward and future markets. These issues will be investigated together with topics related to the opportunities for gaming, the existence and exercise of market power and the impacts on electricity prices. In addition, the framework will serve as an effective test bed for a wide range of policy experiments including those focused on the nature and scope of regulation in the restructured industry. Throughout the proposed work we will implement simulation tools to illustrate the performance of various market designs, rule specifications, regulatory policies, and strategic behavior of various players.

Direct Digital Class-D Audio Amplifier

P. T. Krein,* D. Sarwate,* Z. Song, C. Pascual, X. Geng

Motorola, Inc.; University of Illinois

Conventional "linear" audio amplifiers have low power efficiency. In modern digital audio systems, amplifiers require digital-to-analog conversion, with the associated noise sensitivities and signal problems. Class-D amplifiers operate by direct pulse-width modulated (PWM) switching, and in principle can be free of power loss. Because class-D circuits operate by switching, it is feasible to maintain the audio information in digital form right through to the amplifier output. We explore audio processing to convert from conventional digital formats to PWM. Class-D circuit design methods are being developed to support audiophile performance with very low power loss.

Extended Factors for Linear Contingency Analysis

P. W. Sauer,* K. Reinhard

Grainger Foundation

This project is formulating new computational factors to extend linear contingency analysis to include phenomena such as angle shifts and generator torque changes in response to line outages or closings. The factors build on well-known power transfer distribution factors and line-outage–distribution factors.

Extraction of Low-Order Models from Finite Element Representations of Electromechanical Devices

P.L. Chapman

Grainger Center for Electric Machines and Electromechanics

In designing complicated electromechanical systems it is imperative to have accurate, rapidly executing dynamic models. Traditional lumped-parameter models are not usually as accurate as desired, since they rely on many assumptions in development and parameter extraction. In many respects, the finite element method is a convenient means for eliminating some discrepancies, but the method is very computationally intensive. This project seeks to develop a methodology to extract a computationally non-intensive model from an ordinary finite element representation. The resulting model will retain the salient features of the finite element model, but execute rapidly enough to enable designers to consider many designs and simulate large systems with many devices.

Fully Integrated Switch-Mode Power Supplies

P.L. Chapman, C. Liu

Grainger Center for Electric Machines and Electromechanics

Miniaturization is of supreme interest in all facets of electronics design, and power management is no exception. While power supply components have shrunk considerably in the last decades, the size decrease is limited by the large passive components. Recent developments in MEMS technology have enabled fabrication of microscale inductors and capacitors. Coupled with the integrated switching devices, an entire power converter can be built on a single chip. The integration, which in itself results in a small package, eliminates many of the parasitic effects, and enables one to use higher switching frequency, thereby reducing the size of passive components needed. One interesting application of the technology would be for power MEMS electrostatic actuators, which typically require high voltages (up to hundreds of volts). In this application, a boost converter will be used to convert a logic level voltage to the high voltage needed. The converter and actuator will be entirely on one IC, representing a very compact system.

High Speed Dynamic Simulation Using Krylov Subspace Method

M. A. Pai,* D. Chaniotis

National Science Foundation, ECS 98-03055; Grainger Foundation

The differential-algebraic system of equations of the power system are algebraized using the simultaneous-implicit method, and the resulting system of linear equations at each time step is solved using the generalized minimal residual (GMRES) method. In previous research, the use of preconditioners such as the ILU(s) was found to speed up the convergence. Further enhancement in speed-up was obtained by using the preconditioner only when the number of iterations increased. Various schemes of using LU type preconditioners have been tried with good success for dynamic simulation and trajectory sensitivity computations. Model reduction using Krylov subspace method is currently being investigated.

Hybrid Electric Vehicle Systems

P. T.Krein,* R. A. White* (Mech. & Indus. Engr.), D. Logue

University of Illinois; Grainger Center for Electric Machinery and Electromechanics; Ford Motor Co.; Deere & Co.

A complete hybrid electric car, combining an electric traction system with an engine-generator set, has been built and is now under study in the laboratory and on the highway. The car is designed to meet all performance, safety, and convenience characteristics of standard automobiles, while reducing exhaust emissions by as much as 90% and tripling gas mileage. Objectives are to characterize major subsystems of a practical hybrid car in depth. Tests of efficiency and fuel economy and parametric studies of subsystems have been conducted. A complete system simulation has been prepared. Strategies for system operation and control are being tested through simulation and experiments.

Integrated Security Analysis

P. W. Sauer,*

Power Systems Engineering Research Center (PSERC)

This project is formulating new security analysis tools for operators using existing computational software code with on-line data. Traditional security application programs are used to create historical security results, which will be used to develop learning algorithms that will use both new computational results and historical results. This work is being jointly done with Washington State University.

Interactive Visualization of Electrical Power System Transmission System Capacity

T.J. Overbye,* Doug Wiegmann, Yan Sun

Power Systems Engineering Research Center (PSERC)

One of the major goals associated with restructuring in the electrical power industry is to allow nondiscriminatory access to the high voltage transmission grid. However a key difficulty in achieving this goal has been the fact that the capacity of the transmission grid has a finite but not easily determined value. That is to say, the ability of the transmission system to support additional power transactions is limited by the need to maintain system security. The goal of this project is to develop and apply innovative visualization methods to aid market participants in determining this availability.

Inverse Problems in Power System Dynamics

I.A. Hiskens

EPRI/DoD, NSF

Analysis of power system dynamic behavior frequently takes the form of *inverse problems,* where the aim is to find parameter values that achieve (as closely as possible) a desired response. Examples include parameter estimation, quantifying parameter uncertainty, boundary value problems, and optimal control. The project is developing algorithms for solving such inverse problems. Power system behavior inherently involves interactions between continuous dynamics and discrete events. A systematic *hybrid systems* framework for modeling, analysis and algorithms is being pursued.

Minimizing Failures While Maintaining Efficiency of Complex Interactive Networked Systems

P. W. Sauer,* M. A. Pai, I. Hiskens

EPRI/DoD

This project is task 2 of the overall EPRI/DoD project with this title. This task will formulate the overall design of a link-based mathematical model that can accommodate key functional and structural attributes necessary to analyze the interaction between layered systems. It will use the four-layer power system as the testing ground for applications.

Modeling and Analysis of Transport Systems

I. A. Hiskens, M. A. Pai

National Science Foundation

Many transport industries have much in common with power systems. This proposal seeks to address basic issues that may provide a common framework in terms of analysis, synthesis and optimization of transport networks. Transport systems typically involve distributed agents that are forced to share some common resources. The agents associated with many transport industries exhibit continuous dynamics. However the scheduling of the agents involves discrete events. This project focuses on the modeling and analysis of such hybrid systems that typify transport industries. Current tools for analyzing hybrid systems are inadequate. The project is developing algorithms that address inverse problems (typically design issues) in transport systems.

Modeling and Simulation of Distributed Energy Systems

P. T. Krein,* D. Logue

Grainger Center for Electric Machinery and Electromechanics

The electric Power grid of the future is likely to include "distributed" generation: small units dispersed throughout the system. The work considers a wide range of possible power sources, including engine-generator combinations, batteries, fuel cells, and solar cells. Fast models suitable for system simulation are to be developed. Buffering methods that decouple the dynamics of the power system and the small energy source are being developed. The buffering concept allows the device to act like a resistor over short time intervals.

Motor System Simulation for Dynamic Loads

P. T. Krein,* D. Logue

Grainger Center for Electric Machinery and Electromechanics

This project seeks to develop a general simulation tool for an ac motor in a complex system. The simulation includes electronic motor controls, load dynamics, and interactions between the motor, the load, and the controls. Time-scale models are used to capture both electrical and mechanical behavior. Losses generated by high-frequency switching are included based on behavioral models. The Simulink environment is being used. Sample applications include a complete hybrid automobile system, a dc pump motor operated with a nonlinear controller, and several induction motor applications.

Multi-layer Systems

I. A. Hiskens, P. W. Sauer, M. A. Pai

EPRI/DoD

Communications networks play a significant role in the multi-layer representation of power systems. The communications network model being proposed is based on a conceptual abstraction involving finite channel and node capacities that trigger changes in message transmission delays. Numerical integration of systems that incorporate such variable time delay models is not straightforward. This is especially so when considering the switched (hybrid) nature of system behavior. The project is investigating various techniques to handle variable time delays within numerical integration techniques. An important criterion is that algorithms must be capable of efficiently computing trajectory sensitivities.

New System Control Methodologies

M. A. Pai,* I. A. Hiskens,* A. Nayak, C. L. DeMarco (Univ. of Wisconsin)

Power Systems Engineering Research Center (PSERC)

In this research, we are looking at the effect of dynamic control in the new deregulated environment. In previous research we looked at the AGC in the new restructured environment. Currently we are investigating congestion related problems and their alleviation.

Optimal Bidding Strategies in Transmission Limited Electric Power Markets

T.J. Overbye,* Ian Hiskens, Pedro Correia

National Science Foundation, ECS 00-80279

The electricity industry in the United States and throughout the world is undergoing radical restructuring, with many markets moving from a cost-based paradigm for generation dispatch to a price-based paradigm. These changes require new analysis techniques, both for market participants and for regulators. The goal of this project is the development of a market solution algorithm that allows market participants to determine optimal generation bidding strategies taking into account the constraints imposed by the electric power transmission grid.

Optimal Power Flow Application Issues in the Pool Paradigm

The Italian Fulbright Commission and the U.S. State Department and PSERC

Ettore Bompard, Politecnico of Milano, and George Gross

The research focuses on the application of the Optimal Power Flow (OPF) to competitive markets. Since the OPF is a central decision-making tool its application to the more decentralized decision-making in the competitive electricity markets requires considerable care. There are some intrinsic challenges associated with the effective OPF application in the competitive environment due to the inherent characteristics of the OPF formulation. Two such characteristics are the flatness of the optimum surface and the consequent continuum associated with the optimum. In addition to these OPF structural characteristics, the level of authority vested in the central decision-making entity has major ramifications. These factors have wide ranging economic impacts, whose implications are very pronounced due to the fact that, unlike in the old vertically integrated utility environment, various market players are affected differently. The effects include price volatility, financial health of various players and the integrity of the market itself. We apply appropriate metrics to evaluate market efficiency and how the various players fare. We study the impacts of OPF applications in the Pool paradigm, with both supply and demand side explicitly modeled, also through extensive numerical simulations. The numerical results show the variability of nodal prices and the skew possible in different "optimal" allocations among competing suppliers. Such variability in the results may lead to serious disputes among the players and the central decision-making authority.

Optimal Load Shedding to Alleviate Voltage Instability

I. A. Hiskens, W. Tangmunarunkit

National Science Foundation

Load shedding provides an effective (though drastic) control strategy for alleviating voltage instability. However the disruption to consumers caused by load shedding should be minimized. This project is developing optimal control techniques that are applicable in this hybrid system setting. The aim is to determine locations and shedding times that minimize the total shed load.

Optimized Waveshaping for PM Motor Drives with Unbalanced, Arbitrary, and Asymmetrical Back EMF

P.L. Chapman

Grainger Center for Electric Machines and Electromechanics

By precisely shaping the current in permanent magnet motor drives, considerable improvement in performance can result in terms of efficiency and vibration. Previous work in this area has limitations in that it requires the motor emf to be balanced, symmetrical, and to otherwise be restricted in shape. By eliminating these restrictions, a more flexible control has been developed. An important consequence is that with this control, the motor can be operated with one or more phases absent with only some degradation in power output.

Parameter Values that Induce Marginal Stability

I. A. Hiskens, I. Dobson (Univ. of Wisconsin, Madison)

Power Systems Engineering Research Center (PSERC) and Grainger Foundaiton

Stability limits place restrictions on power system operations. Calculation of these limits is therefore very important, but is also quite difficult. This project is exploring algorithms for determining parameter values that result in marginal stability of a system. (A system is marginally stable for a particular disturbance if the post-disturbance trajectory lies on the stability boundary.) A nonlinear least-squares formulation has been developed to determine a *critical* set of parameter values. Other approaches that a re based on boundary-value problems are being explored.
In order to maintain marginal stability, perturbations in some parameters must be matched by compensating changes in other parameters. The project is developing sensitivity relationships between the two groups of parameters. These sensitivities form the predictor in a predictor-corrector continuation method for tracing the parameter space view of the stability boundary.

Power Electronic Building Blocks Interconnected Network

G. Gross,* P. Krein,* D. Logue

SRI International

Conceptually, Power Electronic Building Blocks (PEBBs) are smart power electronic modules that are superior to conventional power devices in that they have increased sensing, protection control and interfacing capability. This research is directed toward development of a conceptual framework for addressing analysis, design and control issues. The University of Illinois hybrid electric vehicle is intended to be used as a test bed for this framework and other conceptual developments.

Power Flow Solution Space

I. A. Hiskens

EPRI/DoD, Grainger Foundation

Knowledge of the structure of the power flow solution space is important when analyzing the robustness of operating points. Unfortunately, that structure has not been clearly established. As part of this project, a predictor-corrector technique has been developed to assist in exploring the solution space boundary. Using that technique, it has been found that the solution space may contain holes, even for very simple systems. This project is characterizing the solution space structure for various sub-classes of systems. The ultimate aim is to see how far those results can be extended for general systems.

Power Industry Restructuring And Pricing in Siberia

Sergei Palamarchuk and George Gross

Bureau of Educational and Cultural Affairs, US Department of State

The restructuring of the power industry in Russia is underway. The existing nation-wide market is planned to be divided into three regional sectors, one of which will be set up in the Siberian region of the country. The restructuring will allow the market arrangements to take into account the regional characteristics of electricity generation, transmission and consumption.
The project aims to develop the auction mechanism for the wholesale electricity trade in Siberia. Key aspects include the review of the market structures currently in operation, the design of the market forward trade and the associated pricing issues, the procedures for the evaluation of rational bidding strategies for market players and the training of the players in the new environment.

Reactive Load Modeling Impacts on Nodal Prices in Pool Model Electricity Markets

The Italian Fulbright Commission and the U.S. State Department and PSERC

Ettore Bompard, Politecnico of Milano, and George Gross

The project is concerned with the interpretation of the nodal prices in competitive electricity markets based on the Pool paradigm. Such prices are the byproducts of the optimization performed by the independent grid operator (IGO) to determine the centralized economic dispatch taking into account all the transmission network and the physical/operational constraints. The IGO implicitly takes into account congestion considerations in determining the centralized economic dispatch. Under the Pool paradigm, a system marginal price no longer exists and each bus may have a different real and reactive power nodal prices due to line losses and congestion avoidance considerations that can arise when the limit of one or more constraints is reached. The objective is to explore the economic signals provided by these prices and effectively apply them in the design of markets and the *rules of the road* for these markets.

The main focus of the research is on the explicit evaluation of the impacts of the reactive load on the nodal real and reactive prices. We adopt a rather general model for the representation of the reactive load: the reactive load at each node is represented as an affine function of the real power load at that node, i.e., the reactive load is the sum of a constant and a constant power factor component. This model includes as special cases the constant reactive load and the constant power factor load including the case of purely real load corresponding to unity power factor. We investigate the relationship between the real and reactive nodal prices and evaluate the impacts on them of the dual variables due to the various other physical/operational constraints in the system. We study the significance of the nodal price observations and the effective utilization in developing appropriate price signals in the Pool paradigm.

Reliability Tools for Power System Operators

P. W. Sauer,* Tom Overbye

Department of Energy/CERTS

This project is investigating advanced security analysis visualization concepts to enhance the reliability of the interconnected grid. Results from on-line security analysis will be presented and displayed to operators in a format suitable for rapid decision making and for assessing the acceptability of the system state.

Ripple Correlation Control for Power Converters and Motor Drives

P. T. Krein,* P. Chapman,* D. Logue, R. Balog, J. Wells

Grainger Center for Electric Machines and Electromechanics

Ripple correlation control is a new technique that might be unique to power electronic systems. According to this control approach, internal ripple signals in a power converter are correlated with gate drive signals or other internal converter signals. The results provide information about state variables and converter operating points. It is known, for example, that certain correlations can be used to drive a solar power processing converter to its maximum power point. A wide range of applications and related techniques is being explored.

Stability and Optimization of Transformer Tapping

I. A. Hiskens, V. Donde

EPRI/DoD, NSF

Discrete events introduced by on-load tapping of transformers can have a significant affect on the load-end dynamic behavior of power systems. This project is taking a hybrid systems approach to quantifying that behavior. Of particular interest is the stability of systems that involve cascaded tapping transformers. Limit cycles have been observed in such systems. Stability theory for switched ODE systems is being adapted to switched DAE systems, which are more common in power system applications. The project aims to devise optimal switching control strategies for minimizing tap-changer hunting.

Stability of Limit Cycles in Hybrid Systems

I. A. Hiskens

EPRI/DoD

Limit cycles are common in hybrid systems. However the non-smooth dynamics of such systems makes stability analysis difficult. We have been using recent extensions of trajectory sensitivy analysis to obtain the characteristic multipliers of non-smooth limit cycles. The stability of a limit cycle is determined by its characteristic multipliers. Numerous applications have been explored, ranging from on/off control of coupled tanks, through power electronic circuits, to the walking motion of a biped robot. Period-doubling bifurcations have been explored in these latter cases.

The Role of Load Demand in Elasticity in Congestion Management and Pricing

The Italian Fulbright Commission and the U.S. State Department and PSERC

Ettore Bompard, Politecnico of Milano, and George Gross

In the open access transmission regime, the *common carrier* nature of the transmission system may give rise to frequent conditions of congestion. Under such conditions, a violation of one or more physical or operational constraints in the base case or one of the contingency cases is encountered. Congestion may result in certain cases in marked price volatility and leads to price spikes. This is particularly true in competitive electricity markets that lack demand response. In this research, we examine the role that demand responsiveness can play in competitive electricity markets.

Typically, the task of congestion management and pricing is vested in the hands of an independent grid operator (IGO). The IGO uses an optimal power flow (OPF) based tool to determine the necessary actions to relieve the system of the congestion and to determine transmission system usage charges. The actions of price responsive loads may be represented in terms of the customers' willingness to pay. From each customer's demand curve, the elasticity of the load at different prices is known and the benefit function is derived. The load at each bus ceases to be a fixed quantity and becomes a decision variable for the optimization problem of the IGO. In this way, the IGO has additional degrees of freedom in determining the necessary actions to determine congestion relief. The project investigates the impacts of load elasticity in congestion management and pricing. We analyze the salient characteristics of the optimum determined by the IGO with elastic load demand explicitly represented. We evaluate elasticity effects on consumer, producer, merchandising and social surplus. In addition, the demand responsiveness impacts on price volatility in terms of average price and standard deviation are determined and compared to the case without load responsiveness. The increase in market efficiency attainable in the presence of load responsiveness is assessed.

Trajectory Sensitivity as a Tool for Dynamic Security Assessment

M. A. Pai,* T. Nguyen

National Science Foundation, ECS 00-00474; Grainger Foundation

In this research we use trajectory sensitivity information to generate information about critical values of parameters such as clearing time, maximum power transfer, maximum generation etc. before the system becomes unstable. This is done for normal as well as contingency cases. It does not use the traditional energy function methods but rather relies on two fast simulations of the system and the sensitivity model, computing a suitable metric from the latter and extrapolating to compute the critical value of parameters. The technique has been validated on small systems and a theoretical basis is being formulated.

Transmission Congestion Management Schemes: A Comparative Analysis Under a Unified Framework

The Italian Fulbright Commission and the U.S. State Department and PSERC

Ettore Bompard, Politecnico of Milano, and George Gross

The restructuring of the electricity industry has spawned the introduction of new independent grid operators or IGOs, typically called transmission system operators (TSOs), independent system operator (ISOs) or regional transmission organizations (RTOs), in various parts of the world. An important task of an IGO is congestion management (CM) and pricing. This activity has significant economic implications on every market participant in the IGO's region. The research considers the congestion management schemes and the associated pricing mechanism used by the IGO's in five representative systems. These were selected to assess the various CM schemes in use: England and Wales, Norway, Sweden, PJM and California. We developed a unified framework for the mathematical representation of the market dispatch and redispatch problems that the IGO must solve in CM in these various jurisdictions. We use this unified framework to develop meaningful metrics to compare the various CM approaches so as to assess their efficiency and the effectiveness of the market signals provided to the market participants.

Reactive Load Modeling Impacts on Nodal Prices in Pool Model Electricity Markets

The Italian Fulbright Commission and the U.S. State Department and PSERC

Ettore Bompard, Politecnico of Milano, and George Gross

The project is concerned with the interpretation of the nodal prices in competitive electricity markets based on the Pool paradigm. Such prices are the byproducts of the optimization performed by the independent grid operator (IGO) to determine the centralized economic dispatch taking into account all the transmission network and the physical/operational constraints. The IGO implicitly takes into account congestion considerations in determining the centralized economic dispatch. Under the Pool paradigm, a system marginal price no longer exists and each bus may have a different real and reactive power nodal prices due to line losses and congestion avoidance considerations that can arise when the limit of one or more constraints is reached. The objective is to explore the economic signals provided by these prices and effectively apply them in the design of markets and the *rules of the road* for these markets.

The main focus of the research is on the explicit evaluation of the impacts of the reactive load on the nodal real and reactive prices. We adopt a rather general model for the representation of the reactive load: the reactive load at each node is represented as an affine function of the real power load at that node, i.e., the reactive load is the sum of a constant and a constant power factor component. This model includes as special cases the constant reactive load and the constant power factor load including the case of purely real load corresponding to unity power factor. We investigate the relationship between the real and reactive nodal prices and evaluate the impacts on them of the dual variables due to the various other physical/operational constraints in the system. We study the significance of the nodal price observations and the effective utilization in developing appropriate price signals in the Pool paradigm.

7. STUDENT PROJECTS

This section of the report contains information on the graduate students whose major research efforts were supervised by faculty in the Power and Energy Systems Area. While not all of these students received financial aid from the Power Affiliates Program in terms of Research Assistantships, they were all associated with the program through the active involvement of their respective advisors. Those students supported by the Power Affiliates Program received maximum one-half time Research Assistantships for 11 months. The results of each student's work will be made available to all affiliate companies in the form of technical reports. The following students were associated with the Power and Energy Systems Area and their work is described in the following pages:

Balog, Rob (M.S.)
Bartlett, Chris (M.S.)
Chaniotis, Dimitrios (Ph.D.)
Correia, Pedro (Ph.D.)
Dahman, Scott (M.S)
Donde, Vaibhov (M.S.)
Geng, Xin (M.S.)
Grijalva, Santiago (M.S.)
Joung, Manho (M.S.)
Klump, Ray (Ph.D.)
Kukovec, Mike (M.S.)
Liu, Minghai (M.S.)
Logue, Dan (Ph.D.)
Martini, Craig (M.S.)
McElhinney, Seth (Ph.D.)
Mucha, Joe (M.S.)
Munoz, Oscar (M.S.)
Murphy, Christian (M.S.)
Nayak, Anil (M.S.)
Nguyen, Trong (M.S.)
Papenfuss, Cory (M.S.)
Pascual, Cesar (Ph.D.)
Reinhard, Karl (Ph.D.)
Sun, Yan (M.S.)
Tangmunarunkit, Worapot (M.S.)
Tao, Shu (Ph.D.)
Weber, Jamie (Ph.D.)
Wells, Jason (M.S.)
West, Sean (M.S.)

Rob Balog

Date of Birth:	September 18, 1974
Place of Birth:	Edison, New Jersey
B.S.:	1996, Rutgers University
M.S.:	In progress
Professional Interests:	Power electronics, analog circuits, visual environment controls, building/home automation.

Coupled Magnetics Applications

Rob Balog with advisor P. T. Krein

Supported by Grainger CEME

ABSTRACT

Coupled magnetic components, including transformers, coupled inductors, and electromechanical devices, can be difficult to model and to apply in circuits. This project seeks to develop fundamental understanding of how coupled magnetic elements, particularly, coupled inductors, compare with uncoupled components in filter applications. We believe the results will give better guidance about models for parasitic capacitances and other nonlinear circuit effects in all types of magnetic components.

Chris Bartlett

Date of Birth:	December 13, 1970
Place of Birth:	Chicago, IL
B.S.:	May 1994, University of Illinois
M.S.:	October 2000, University of Illinois
Professional Interests:	Power systems and generation.

Saturation and Hysteresis Modeling

Chris Bartlett with advisor P. W. Sauer

Supported by the Grainger Foundation Endowments

ABSTRACT

This project is investigating mathematical models for saturation and hysteresis. Analytical models are being sought that correctly capture the energy lost due to hysteresis while maintaining proper energy conversion equations. Initial work is focusing on transformers, using piecewise linear methods.

Dimitrios Chaniotis

Date of Birth:	October 31, 1973
Place of Birth:	Athens, Greece
B.S.:	October 1996, National Technical University of Athens
M.S.:	August 1998, University of Illinois
Ph.D.:	May 2001 (expected), University of Illinois at Urbana-Champaign
Professional Interests:	Power systems, automatic control and computer engineering.

Krylov Subspace Methods in Power Systems Model Reduction

Dimitrios Chaniotis with advisor M. A. Pai

Supported by the National Science Foundation Grant NSF ECS 00-00474
and Grainger Foundation

ABSTRACT

The analysis and simulation of large power systems require extensive computer resources. In practice, detailed analysis is focused on a restricted part of the network called the study area, whereas the rest of the network called the external area can be modeled with less accuracy. Therefore its size may be reduced and the computational effort is lessened. In this research we examine the application of Krylov subspace techniques for the reduction of the linearized power system. A theoretical comparison with modal model reduction is made, and experiments are carried out on a 50-machine system and a 245-machine system.

Pedro Correia

Date of Birth:	July 29, 1969
Place of Birth:	Lisbon, Portugal
B.S.:	July 1993, Instituto Superior Tecnico
M.S.:	May 1996, Instituto Superior Tecnico
Ph.D.:	In progress
Professional Interests:	Power System Analysis; Competitive Electricity Markets; Power System Relaying

Strategic Equilibria in Competitive Electricity Markets

Pedro Correia with advisor T. J. Overbye

ABSTRACT

The emergence of competitive electricity markets has given rise to the problem of strategic bidding by market participants in the pursuit of profit maximization. Moreover, given the simultaneous action of all participants, the so-called Nash equilibria are the points in the bidding space that simultaneously satisfy the objective of all participants. The work focuses on the problem of finding multiple pure- and mixed-strategy Nash equilibria in an electricity market in which we assume that the market participants have complete information about cost functions. In addition, we assume that a central decision maker (ISO) dispatches the market using an OPF tool. We use the Individual Welfare Maximization, or IWM, that was previously developed for the purpose of finding a pure-strategy equilibrium and we further develop it for the multi-equilibria problem. This problem requires searching for solutions in the space regions defined by the line constraints and, due to its exponential-size nature, we use specific problem reduction techniques.

Scott R. Dahman

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Place of Birth:	St. Louis, MO USA
B.S.:	May 1993, Washington University
M.B.A	May 1994, Washington University
M.S.:	In progress, expected May 2002
Professional Interests:	Power System Economics, Demand Side Management

Demand Side Hedging of Risks Associated with Power Market Volatility

Scott R. Dahman with advisors T. J. Overbye and P. W. Sauer

Supported by Grainger Endowments

ABSTRACT

Spot market prices in restructured electricity markets are typically much more volatile than those of traditionally regulated markets, exposing power consumers to greater financial risk. Such risk may be mitigated through demand-side practices such as load leveling, two-sided auctions, long-term supply contracts, ownership of distributed generation, or financial hedging in options and futures contracts. This project specifically examines the ways that power consumers can reduce financial risk through hedging contracts. It reviews the principles of designing a financial hedging strategy, then applies those principles to a specific environment of an industrial power consumer on an IEEE 30-bus network. Methods for expanding the solution to larger networks are also discussed.

Vaibhav Donde

Date of Birth:	July 17, 1977
Place of Birth:	Thane (Maharashtra), India
B.S.:	June 1998, V.J.T.I., Mumbai, India
M.S.:	October 2000, University of Illinois at Urbana-Champaign
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Professional Interests:	Power systems, control systems

Stability and optimization of transformer tapping

Vaibhav Donde with advisors I. H. Hiskens and M. A. Pai

Supported by PSERC

ABSTRACT

Power systems have inherent interactions between continuous and discrete dynamical events. One of the devices that introduce discrete dynamics in power systems is OLTC (on load tap changer). In this work, behavior of a discrete tap-changer and cascaded tap-changers is studied and strategies for transformer tapping are developed that alleviate a need for load shedding. Stability theory for switched ODE systems will be applied with any modifications to switched DAE systems that are common in power system applications. Finally, optimal switching control methodologies are planned to be devised for tap-changer related controls.

Xin Geng

Date of Birth:	October 20, 1977
Place of Birth:	Tianjin, P. R. China
B.S.:	July 2000, Tsinghua University, Beijing, P. R. China
M.S.:	In progress
Ph.D.:	
Professional Interests:	Power Electronics, Control and Digital Signal Processing

Multi-Carrier Pulse Width Modulation Control

Xin Geng with advisor P. T. Krein

Supported by the Grainger Center for Electric Machinery and Electromechanics and by the Motorola-UIUC Center for Communications

ABSTRACT

Pulse width modulation (PWM) has been widely used in power electronics to improve output waveform fidelity while achieving high converter efficiency. Conventional PWM methods use a ramp or triangle as a carrier signal to generate a pulse width sequence. However, this approach does not provide direct support when a high-frequency ac link is desired, mainly because of the existence of dc and base-band components of the modulating signal. A high-frequency ac link would permit the use of miniature transformers for isolation and voltage gain. In this work, a multi-carrier PWM method is being developed to overcome some of the deficiencies inherent in the conventional approach. The new technique offers the possibility of inverters with fewer power conversion stages, device simplification, and high-frequency ac links. Mathematical analysis has been performed to explain the properties of the multi-carrier approach, and computer simulations have further confirmed the theoretical analysis. More general multi-carrier modulation techniques, signal recovery rules, and distortion reduction methods are being explored.

Santiago Grijalva

Date of Birth:	November 25, 1970
Place of Birth:	Quito-Ecuador
B.S.:	1994, National Polytechnic University – Ecuador
M.S.	July 1997, Army Polytechnic University – Ecuador, Information Systems
M.S.:	August 1999, University of Illinois, Electrical Engineering
Ph.D.:	In progress
Professional Interest:	Real-time control of power systems, power system economics, information systems.

Computation of Available Transfer Capability In Power Systems

Santiago Grijalva with advisor P. W. Sauer

Supported by Grainger Endowments

ABSTRACT

The project is investigating enhancements to current methods for computing Available Transfer Capability (ATC). New algorithms to incorporate the voltage effect in large transactions are studied. The work is focusing on power flow sensitivities, estimation of maximum loadability, linear/non-linear computation of ATC and boundaries of static load flow solution

Manho Joung

Date of Birth:	December 13, 1972
Place of Birth:	Seoul, Korea
B.S.:	February 1995, Seoul National University, Seoul, Korea
M.S.:	February 1997, Seoul National University, Seoul, Korea
Ph.D.:	In progress
Professional Interests:	Power System Economics

Construction and Analysis of Nash Equilibrium Properties in Electricity Markets

Manho Joung with advisor G. Gross

Supported by National Science Foundation

ABSTRACT

We apply a game theoretic approach for the construction of optimal bidding strategies in competitive electricity markets. We model various physical and economic aspects of electricity systems and markets, respectively. We construct and then analyze the properties of Nash equilibrium (equilibria) for such markets. Various examples on smaller systems are being developed to assess the issues with extensions to larger systems. With the capacity constraints on generators ignored, the unique Nash equilibrium is guaranteed. On the other hand, under maximum generation quantity constraints, the best response curve of a constrained player has a discontinuity and, as such, there is no guarantee for the existence of a Nash equilibrium. We are also extending the results when the uncertainty in load demand is explicitly represented.

Ray Klump

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Place of Birth:	Berwyn, IL
B.S.:	May 1993, University of Illinois
M.S.:	May 1995, University of Illinois
Ph.D.:	October 2000
Professional Interests:	Power systems.

Path-Independent Power System Voltage Stability Analysis

Ray Klump with advisor T. J. Overbye

Supported by PowerWorld Corporation

ABSTRACT

The overall goal of this project is the development of a computationally efficient method for power system voltage stability assessment. The approach is to use energy methods for path independent assessment. The key computational challenge in this approach is determining the appropriate low voltage solutions. This challenge arises because for an n bus power system there can be up to a maximum of 2^{n-1} separate power flow solutions. Fortunately, only at most the n-1 type-one solutions need to be determined. Each of these solutions, if it exists, can usually be found with a low initial voltage guess at a particular bus i; the solution found with a low voltage guess at bus i will therefore be referred to as the bus i solution. The percent loading associated with the bus i energy measure then provides measure of the voltage stability in the region about bus i. Nevertheless, calculating all of these n-1 solution would still require computation equivalent to approximately n-1 power flow solutions, which would clearly be computationally unacceptable. Research is therefore focused on computationally efficient methods for determining these solutions.

Mike Kukovec

Date of Birth:	August 18, 1971
Place of Birth:	Winfield, IL
B.S.:	May 1999, University of Illinois
M.S.:	May 2000, University of Illinois
Professional Interests:	Consulting engineering for power generation, transmission, distribution.

Power Transmission Line Equivalent Circuit Models In Transient Analysis

Mike Kukovec with advisor P. W. Sauer

Supported Grainger CEME and the Electrical and Computer Engineering Department

ABSTRACT

Transient analysis techniques of power transmission line events lack a simple model that will adequately represent a real, lossy system. While models do exist that can accurately predict transient behavior, they are valid only for lossless cases. Other models exist that take losses into consideration and provide accurate steady state analysis, but are not valid for transient study.

By comparing several equivalent circuit models of power transmission lines for both lossless and lossy cases, possible techniques for accurate transient and steady state analysis will be discussed. Equivalent circuit models include the "PI", "T", "Inverted-L" and "Backwards-Inverted-L." The discussion will also focus on the number of segments used in the circuit models in relation to solution accuracy, and examination of system eigenvalues and their relationship to simulation results.

Minghai Liu

Date of Birth:	January 07, 1974
Place of Birth:	Zhoushan City, Zhejiang province, P.R.China
B.S.:	July 1997, Tsinghua University, P.R.China
M.S.:	July 2000, Tsinghua University, P.R.China
Ph.D.:	In Progress
Professional Interests:	Power System Analysis and Power Economics

The role of Transmission Rights in Electricity Markets

Minghai Liu with advisor G. Gross

Supported by Grainger Foundation and PSERC

ABSTRACT

A key requirement for smoothly functioning electricity markets is the availability of firm transmission services. A new tool for ensuring such services uses the concept of transmission rights. We explore the basic principles of Firm Transmission Rights (FTRs) and analyze their characteristics. A different approach is based on the definition of Flowgate Rights (FGRs). We review the FGR concepts and compare it with the FTR notion. The impacts of system parameters such as PTDFs on the application of transmission rights are also studied.

Daniel Logue

Date of Birth:	July 28, 1970
Place of Birth:	Pana, IL
B.S.:	January 1996, University of Illinois
M.S.:	October 1997, University of Illinois
Ph.D.:	October 2000
Professional Interests:	Control and simulation of power electronic systems and electrical drives.

Power Electronic Building Blocks: Concept Definition, Simulation and Application

Daniel Logue with advisor P. T. Krein

Supported by SRI International and DOE

ABSTRACT

The Power Electronic Building Block (PEBB) concept involves the control and interfacing of intelligent power electronic modules. Examples of PEBB modules include rectifiers, inverters and dc-dc converters. Local control exists to provide module functionality and to deal with fast local contingencies such as faults. A networked system of PEBB modules is termed PEBB*NET*. In addition to the local control provided by each PEBB module, the PEBB*NET* is managed by a centralized controller labeled the Coordinator. The Coordinator's job is to create a synergism between the various PEBB modules within the network to enhance or maintain global operating characteristics such as overall efficiency and performance, and system-wide stability.

Craig Martini

Date of Birth:	December 26, 1976
Place of Birth:	Middletown, Ohio
B.S.:	May 1999, Rose-Hulman Institute of Technology, Terre Haute, IN
M.S.:	August 2000
Professional Interests:	Power and control systems.

Virtual Reality and Two-dimensional Visualization Methods Applied to Power Systems

Craig Martini with advisor T. J. Overbye

Supported by the National Science Foundation and Grainger Foundation

ABSTRACT

Displaying power system information in an effective manner can be difficult because of the complexity of power systems. As the electricity industry becomes increasingly competitive, information concerning electric system capacity and constraints is a valuable commodity. The goal of this work is to develop new methods of visualization using two-dimensional displays and a three-dimensional virtual environment to assist players in the electricity industry in extracting this knowledge from a large set of power system data.

Seth McElhinney

Date of Birth:	May 12, 1975
Place of Birth:	Los Angeles, California
B.S.:	March 1998, Terre Haute, Indiana
M.S.:	March 2001, Terre Haute, Indiana
Ph.D.:	In progress
Professional Interests:	Electric machines, simulation, finite element analysis

Switched Reluctance Machine Vibration and Noise Mitigation

Seth McElhinney with advisors P. L. Chapman and P. W. Sauer

Supported by Grainger Foundation

ABSTRACT

This project focuses on how to mitigate switched reluctance machine vibrations in a practical and cost-effective way. An ideal switched reluctance machine would produce minimal vibration, acoustic noise, and low ripple torque, in addition to being simple, rugged, and efficient. Two promising approaches to this ideal are optimization of control algorithms and optimization of drive power electronics.

Joe Mucha

Date of Birth:	January 29, 1975
Place of Birth:	West Berlin, Germany
B.S.:	December 1998, Andrews University
M.S.:	December 2000, University of Illinois (Mechanical Engineering)
Current Status:	Ford Motor Company, Dearborn, MI

Control Strategy of Series Hybrid Electric Vehicles

Joe Mucha with advisor P. T. Krein

Supported by the Grainger Center for Electric Machinery and Electromechanics

ABSTRACT

Air pollution in major cities has led to the need for vehicles that produce fewer emissions. On alternative to conventional vehicles is the hybrid electric vehicle. Hybrid vehicles use energy in both fuel and electric form. The University of Illinois has developed a series hybrid electric vehicle that is essentially an electric car with an onboard engine and generator set to recharge the batteries. The goal of the project is to develop a highly efficient full size sedan that is capable of achieving a fuel economy of 70 miles per gallon with low exhaust emissions. The total efficiency of the vehicle is the product of the efficiencies of all the components in the system. Most of the efficiencies cannot be easily altered. However the engine efficiency varies from 10%-40% and the battery pack efficiency varies from 25%-90% depending on use. We have studied different techniques to determine the tradeoffs between the engine and batteries in order to maximize the product of their efficiencies. This research has been used to develop a control strategy for the engine and generator set. Computer simulations, chassis dynamometer tests, and on-road tests were used to verify the performance of several families of control strategies for the vehicle.

Oscar F. Muñoz

Date of Birth:	October 16, 1975
Place of Birth:	Mexico, D.F., Mexico
B.S.:	February 1998, Instituto Politécnico Nacional
M.S.:	In progress
Professional Interests:	Power systems operation and control, utility restructuration, computational algorithms.

Market Power Analysis of Electric Power Systems

Supported by Fulbright Fellowship

ABSTRACT

The goal of this project is to determine the amount of potential market power in bulk electricity markets, with the explicit consideration of the transmission system. In general, market power is the ability of a particular seller or group of sellers to maintain prices profitably above competitive levels for a significant period of time. The restructuring of the electric industry has encouraged competitive markets with the objective of reaping the benefits of lower prices and innovation that competition can provide. Such benefits are not attainable when a player utilizing the electric transmission system may exercise such market power.

Christian Murphy

Date of Birth:	March 11, 1976
Place of Birth:	Chicago, IL
B.S.:	June 1998, Williams College
M.S.:	May 2000, University of Illinois
Current Status:	Graduate Student at Alexandria Research Institute, Alexandria, VA

Evaluation of a Resonant Converter for Plasma Display Panel Powering

Christian Murphy with advisor P. T. Krein

Supported by LG Electronics

ABSTRACT

Plasma display panels (PDPs) are beginning to replace the currently used bulky television and computer displays with a much thinner flat-panel alternative. A PDP acts as a capacitive load that requires a pulsed dc driving waveform with a magnitude of around 250 V at a frequency of up to 100 kHz. With a capacitive load, a significant portion of the driving energy is recoverable. A resonant converter is used to supply and recover the energy to the PDP. A recovery efficiency is defined as the ratio of the energy supplied to the energy recovered from the load.

The converter was dynamically modeled using Simulink to isolate the loss mechanisms. Switching device models were developed and used to gain an understanding of the effects of the device capacitance. In the high voltage low current (20 mA) conditions of the converter, the device capacitance can be a source for significant loss as it must be charged and discharged 100,000 times a second. Both experimental and computational results confirm this. The conventional practice of placing two or more devices in parallel to reduce device resistance has, in this case, the counterintuitive effect of decreasing the recovery efficiency by increasing total device capacitance. An IGBT was found to have the greatest recovery efficiency of as high as 87%.

Anil Nayak

Date of Birth:	September 19, 1977
Place of Birth:	Belleville, NJ
B.S.:	June 1998, V.J.T.I., Mumbai, India
M.S.:	in progress
Professional Interests:	Power system analysis, competitive electricity markets

Optimal Power Flow Model Incorporating FACTS Devices for Congestion Management

Anil Nayak with advisor M. A. Pai

Supported by PSERC

ABSTRACT

FACTS devices can improve system loadability and power exchange capability. This, by way of bolstering transmission infrastructure, assumes significance in a deregulated electricity industry. The goal of this work is to develop OPF models taking into account nonlinearities in the constraint equations and changes in line capacities, losses and transmission charges due to the introduction of FACTS devices.

Trong Nguyen

Date of Birth:	September 10, 1966
Place of Birth:	Vietnam
B.S.:	January 1998, University of Illinois
M.S.:	August 1999, University of Illinois
Ph.D.:	In progress
Professional Interests:	Power system stability, control, and computation.

Dynamic ATC Computations Using Sensitivity Functions

Trong Nguyen with advisors M. A. Pai and I. H. Hiskens

Supported by the National Science Foundation

ABSTRACT

In this research we wish to investigate the use of trajectory sensitivities as a tool to compute dynamic available transfer capabilities (ATC) in a power system. Currently, transient energy function (TEF) method is being proposed but its major drawback is the need to compute the controlling unstable equilibrium point (u.e.p.) to obtain the critical energy. However, the TEF is a very useful concept and can be used as a metric in computing an estimate of t_{cr} without computing the u.e.p. Initial results are very encouraging. The sensitivity approach is independent of modeling complexity. Sensitivity of power transfer over tie lines with respect to generation for a set of contingencies gives useful information regarding rescheduling of generation if found necessary. This concept has been successfully tested on a 10-machine, 39-bus system. The idea can be extended to compute dynamic ATC.

Cory Papenfuss

Date of Birth:	November 28, 1975
Place of Birth:	Dubuque, IA
B.S.:	University of Alaska, Fairbanks
M.S.:	December 2000, University of Illinois
Current Status:	Graduate Student at VPI, Blacksburg, VA

Measurement and Control of Series Hybrid Electric Vehicle (HEV) Batteries and APU Charging System

Cory Papenfuss with advisor P. T. Krein

Supported by Grainger CEME

ABSTRACT

The charging and monitoring of an HEV's transient energy source presents a number of power flow measurement and control issues. Because the transient power requirements of the traction system vary widely from large negative power during regenerative braking to almost full battery power capacity, large currents from the battery cause the dc bus voltage to vary significantly during normal operation. Normal control of the engine-generator's rectifier regulates either output voltage or current; either of these regulations cause large variations in generator power as the battery bus voltage fluctuates. To address this, an analog controller to regulate the voltage-current product was used to control the generator power and effectively isolate the transient traction power requirements from the engine-generator power delivery. The speed-torque curve for the car's diesel engine needed to be considered. Because an internal combustion engine has an increasing torque curve as speed increases, a true constant power load is inherently unstable. In addition to the power regulation, a "load-droop" characteristic was added to the rectifier control to stabilize the system. The result was a stable and efficient auxiliary power unit for a hybrid electric vehicle.

Cesar Pascual

Date of Birth:	June 15, 1968
Place of Birth:	Teruel, Spain
B.S.:	December 1992, Polytechnical University of Catalonia
M.S.:	January 1997, University of Illinois
Ph.D.:	December 2000, University of Illinois
Current Status:	Engineering Staff position, Madrid, Spain

All-Digital Audio Amplifier

Cesar Pascual with advisor P. T. Krein

Supported by Motorola

ABSTRACT

Audio amplifiers have traditionally been analog, built upon Class-A, -B or -AB stages. All of these linear amplifiers exhibit relatively low efficiencies, mainly because their power transistors are always in mid-conduction. More recently, some switching amplifiers have overcome the efficiency problem by using pulse width modulation (PWM) and Class-D stages. This allows the power transistors to work either in the on or off state, and increases the efficiency drastically. However, most of these solutions have difficulties with radiated interference and with offering a high audio quality. If the audio source is digital, as it is the trend nowadays, it would seem more logical to generate the PWM signal directly from the digital input, without using D-to-A or A-to-D conversion. Careful digital signal processing can improve the audio quality, reduce the interference, and keep the efficiency at its maximum. This project investigated several approaches to the concept of an all-digital audio amplifier. It is shown that natural sampling PWM offers low distortion. Several processes for uniform to natural sampling were introduced. Processes for digital noise shaping, to keep quantization noise effects low, were added. The processed signals were used with an inverter to create the digital class-D stage. An experimental system was shown to exceed the audio performance of conventional class AB designs, with much lower power loss.

Karl Reinhard

Date of Birth:	August 18, 1960
Place of Birth:	Camp Hanford, Washington
B.S.:	May 1982, United States Military Academy
M.S.:	May 1992, University of Texas at Austin
Ph.D.	In progress (currently on leave)
Professional Interests:	Advanced linear method for contingency analysis.

Advanced Security Analysis

Lieutenant Colonel Karl Reinhard, U.S. Army, with advisor P. W. Sauer

Supported by the U.S. Army

ABSTRACT

This project is investigating advanced linear methods for predicting results of contingency analysis in available transfer capability computation. Goals include the identification of critical elements which lead to cascading failures. Current work is focusing on line outage angle factors and the associated line closure generator current distribution factors.

Yan Sun

Date of Birth:	December 17, 1974
Place of Birth:	Songyuan, Jilin Province, P. R. China
B.S.:	1997, Tsinghua University, Beijing, P. R.
M.S:	2000, 1997, Tsinghua University, Beijing, P. R.
Ph.D.:	In progress
Professional Interests:	Power System Simulation and Electricity Markets

Electric Power System Visualization

Yan Sun with advisor T. J. Overbye

Supported by Grainger Foundation and PSERC

ABSTRACT

As the electricity industry becomes increasingly competitive, knowledge concerning the capacity and constraints of the electric system will become a commodity of great value. Electricity markets can be fast changing; understanding the implications of these changes before others can give an important competitive advantage. The goal of this project is to develop innovative methods to assist players in the electricity industry to extract and visualize this knowledge from the large set of power system data. The project is exploring the use of techniques for knowledge extraction utilizing two-dimensional displays, as well as the use of an interactive three-dimensional environment.

Worapot Tangmunarunkit

Date of Birth:	December 19, 1976
Place of Birth:	Muang, Yala, Thailand
B.S.:	May 2000, University of Wisconsin at Madison
M.S.:	In progress
Professional Interests:	Power System, Control system.

Optimal Load Shedding Against Voltage Instability

Worapot Tangmunarunkit with advisor I. H. Hiskens

Supported by Grainger Foundation and National Science Foundation (NSF)

ABSTRACT

With the limiting factors of the transmission system, it is common that the voltage of the system will be unstable. Load shedding is one corrective mechanism preventing power system from voltage collapse. Load shedding, however, should be implemented in an optimal way in order to satisfy most customers. Since the behavior of power system involves complex interaction between continuous dynamics and events of discrete nature, hybrid model is to be used to capture the system behavior. With the different orders of the events and parameters in hybrid system, the optimization problems will take on a combinatorial nature. The local minimum of each continuous section of cost function needs to be searched in order to find the global optimization.

Shu Tao

Date of Birth:	March 19, 1969
Place of Birth:	Changchun, China
B.S.:	July 1992, Tsinghua University
M.S.:	July 1995, Tsinghua University
Ph.D.:	October 2000
Professional Interests:	Power system operation and control

Transmission Congestion Management in Multiple Transaction Networks

Shu Tao with advisor G. Gross

Supported by Grainger Endowments and PSERC

ABSTRACT

At the time when the transmission system can not transfer more power from a source point to a load point without violating one or more physical and/or operating constraints of the system, transmission congestion occurs. While transmission congestion does not impose a major issue under the vertical integrated utility (VIU) environment, it becomes a much more critical issue for the system security in the open access regime, in which sellers and buyers of electricity independently arrange bilateral power transactions with each other according to their own interests, and the transmission network is used in the *common carrier* mode by the Independent Grid Operator (IGO) to accommodate these various transactions. The increasingly enlarged number of such market-driven transactions is bound to result in more serious congestion and more frequently. Therefore, in the transaction-based environment, congestion is a very important issue that has direct impacts on the system reliability and must be addressed appropriately.

We first reviewed the existent congestion management schemes. The pros and cons of these schemes are analyzed and discussed. On the basis of the multi-transaction framework previously constructed, we proposed a new two-stage congestion management scheme for a multiple transaction network. This scheme consists of the congestion allocation stage and the congestion relief stage. The congestion allocation stage determines each transactions contribution to the overload congestion. The congestion relief stage formulates the IGO's least-price congestion relief problem as an OPF, in which the IGO acquires congestion relief services to remove each transactions congestion burden accordingly. A marginal-cost-pricing scheme is also developed to determine the charges to each transaction for its actual usage of the system. This proposed scheme was implemented in various IEEE test-cases to illustrate its desirable characteristics.

Jamie Weber

Date of Birth:	June 13, 1973
Place of Birth:	Platteville, WI
B.S.:	May 1995, University of Wisconsin-Platteville
M.S.:	January 1997, University of Illinois
Ph.D.:	January 2000, University of Illinois
Current Status:	PowerWorld Corporation Urbana, IL

A Simulation-Based Approach to the Optimization of Electricity Markets Including Consumer and Full Transmission System Modeling

Jamie Weber with advisor T. J. Overbye

Supported by the Grainger Foundation

ABSTRACT

The restructuring within the electric power industry throughout the world has created a need for innovative new approaches to power system analysis. Most importantly, new economic analysis tools are needed by the industry. One tool that will be of interest is an electricity market simulator.

The optimal power flow (OPF) algorithm that was developed during my master's degree has been enhanced to include the modeling of consumer price elasticity. (In other words, consumers who change their consumption based on the price signals they receive). Using this enhanced OPF, we are able to determine the optimal behavior of the market from a global perspective. Over the past year, we have developed techniques to more closely simulate an individual's behavior explicitly within this OPF framework. Nash equilibrium as well as market oscillations have been observed. Participants in the market could use this tool for economic benefit, while regulators could use this to study how participants may behave under a given set of market rules.

Jason Wells

Date of Birth:	October 7, 1978
Place of Birth:	Cherry Valley, Illinois
B.S.:	May 2000, University of Illinois
M.S.:	In progress
Professional Interests:	Electric machinery, medicine, and law

Linear Induction Machine Design

Jason Wells with advisor P. L. Chapman

Grainger Center for Electric Machinery and Electromechanics

ABSTRACT

This project is investigating linear induction machine design techniques and the potential development of an educational laboratory component.

Sean West

Date of Birth:	December 17, 1974
Place of Birth:	Denver, CO
B.S.:	December 1997, University of Illinois
M.S.:	May 2000, University of Illinois
Current Status:	Th!nk Division, Ford Motor Company, Dearborn, MI

Performance Evaluation of Switched Capacitor Battery Equalizer

Sean West with advisor P. T. Krein

Supported by the Power Affiliates Program

ABSTRACT

Battery applications, including large energy storage systems involving lead-acid chemistry, are experiencing rapid growth. New generations of electric and hybrid vehicles and uninterrupted power supplies (UPS) place extreme requirements on batteries. In these applications, the batteries must be placed in series to produce enough power. When batteries are placed in series, one might expect that the complete battery pack will operate as the sum of the *n* batteries from which it was constructed. This is not the case. Voltage imbalance in a series string can lead to degradation of an individual battery cell, leading in turn to premature failure of the entire pack. An *equalization* process to balance the batteries is needed to help avoid this failure mode. In this project, several sets of batteries were subjected to accelerated life testing to compare the effects of equalization methods. It was found that batteries should be held to a match within about 15 mV to avoid long-term imbalance. Fast cycling is especially hard on batteries. In a fast cycle test, less than 10% of the expected life was actually achieved without equalization or when the equalization process was too gradual to keep up with the cycle. In high-temperature tests, equalization methods helped maintain the expected life. An active equalization method developed at UIUC in an earlier project shows considerable promise as a possible low-cost precision equalization approach suitable for many types of batteries.

8. LABORATORY FACILITIES

The Power Area has assembled some of the nation's finest facilities for experimental and computer-based research and teaching. Both undergraduate and graduate students can take advantage of these facilities. These laboratories have generated wide interest.

The **Grainger Power Engineering Software Laboratory** is located near the office areas on the third floor of Everitt Laboratory. The Laboratory has ten advanced personal computers and workstations. All stations are connected to the campus network and Internet.

A major objective of the laboratory is to develop an extensive library of commercial software and large-scale data bases for power area applications. Software is based on the Linux operating system and on Windows 2000. Some of the commercial software packages currently in use include:

Mathematica (an advanced symbolic mathematics package)
SYMNON (system analysis and design software)
IPFLOW (Interactive Power Flow)
SSSP (Small Signal Stability Analysis)
MatLab and Simulink
PSS/E (Power Technologies Inc. Software Package)
PowerWorld
Power System Tool Box (PST Version 2.0)

The software library is being expanded continually.

The **Grainger Electrical Machinery Laboratory** is located on the ground floor of Everitt Laboratory. This facility is primarily for undergraduate teaching, and is used for ECE 333, ECE 369, many ECE 345 projects, and the Advanced Electric Vehicle Program. Ten self-contained machinery workstations are available. Each has an integral horsepower machine set, digital wattmeters, oscilloscope, optical tachometer, torque sensor, and electronic support instruments. Transformers, resistor units, capacitors, SCR circuits, small electronic and power FET units are provided in support of the full range of experiments in all aspects of power. The facility has a dedicated 225 KVA three-phase supply and a 50 kW d-c rectifier bank.

The **Advanced Power Applications Laboratory** is adjacent to the Grainger Electrical Machinery Laboratory. This laboratory serves as a general research facility for all hardware aspects of power electronics, machines, and power systems. The lab shares motor test sets with the Machinery Lab. Additional equipment is available for the study of harmonic effects, high-performance switching converters, and digitally controlled drives. This laboratory's computer facilities communicate with the Grainger Power Engineering Software Laboratory through the Internet.

9. DIRECTORY

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